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EARTH STATION DESIGN AT 12/14 GHz

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16. Abstract

A study of two issues: The design of a 12/14 GHz wideband two-way earth station located in Denver, Colorado, and compatible with the CTS, PSCS, and SYNCOM IV satellites; secondly, the search for a suitable site for the earth station in the vicinity of the Denver Network Coordinating Center located at the Diamond Hill Building Complex. A common design was found to be satisfactory for all satellites and a suitable site location was pinpointed.

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PREFACE

OBJECTIVE

This study examines the overall system design requirements and the tradeoffs within the system design for a wideband 12/14 GHz earth station. Operation of a fixed station with the Communications Technology Satellite (CTS), a potential Public Service Communications Satellite (PSCS), and the possible SYNCOM IV Satellite are considered.

In addition, this study reports on the considerations involved in locating a fixed satellite station adjacent to the Denver Network Coordinating Center.

SCOPE OF WORK

The study of earth station requirements and tradeoffs was carried out with the following approach:

1. summarize spacecraft characteristics;
2. summarize range of video parameters required;
3. assess impact of rain attentuation at Denver for fixed station;
4. carry out link calculations set producing G/T and EIRP requirement; and

5. carry out optimization between:
   (a) antenna size;
   (b) receiver noise figure; and
   (c) transmitter power.

The site location study examined alternative locations for a fixed two-way wideband 12/14 GHz earth station in the vicinity of the Denver Network Coordinating Center. The following procedure was utilized:

1. For the optimum fixed earth station (determined in first phase of the study) compute worst case foundation loads that would be generated at 125 MPH with a 1.5 safety factor.
2. Select locations on or around the Diamond Hill building that could perhaps withstand the foundation loads.
3. Investigate these sites for:
   (a) ease of cable/waveguide entry to building;
   (b) availability of AC power required; and
   (c) accessibility for maintenance and observation.
4. Negotiate with the landlord for permission to construct.
5. Investigate in detail the structural arrangements to mount antenna with survival at 125 MPH and 1.5 safety factor.
6. Investigate the necessity for arranging special protection against radiation.

CONCLUSIONS

1. The three satellite systems considered: CTS, PSCS, and SYNCOM imposed almost identical constraints on the design of the earth station as far as required EIRP and G/T were concerned.
2. The impact of rain attenuation was an important factor but for the link availability selected (99.95%) did not have drastic cost impact.
3. High quality video performance (48 dB signal to noise) could be achieved by a station ten feet in diameter with a Ga As FET preamplifier and a 200-watt TWT high-power amplifier.

4. The optimum-design earth station can be located at a roof-top site at the Diamond Hill building complex, adjacent to the Denver Network Coordinating Center. Although the final site is not quite as accessible as one of the proposed sites, it does satisfy the building landlord's asthetic requirements.

SUMMARY OF RECOMMENDATIONS

1. That the desired link availability be 99.95%.
2. That the desired video signal-to-noise be 48 dB peak-to-peak, video-to-weighted RMS noise when all link margins are exercised either on the uplink or downlink.
3. That the optimum earth station configuration be a combination of:
   (a) 10-foot diameter cassegrain-feed antenna;
   (b) 4 dB NF Ga As FET preamplifier; and
   (c) 200-watt TWT
4. That the earth station be located on the roof of Building B to the west side.

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SPACECRAFT REQUIREMENTS

The performance parameters for the Communications Technology Satellite (CTS) are known whereas those for the Public Service Communications Satellite (PSCS) and SYNCOM IV are in the planning stage at this time and subject to variation in the future.

CTS Characteristics

The overall characteristics are summarized in Table I below.

Table 1. CTS Spacecraft Parameters

Characteristic	Value
Uplink	
Bands of operation (GHz)	14.010 - 14.095
	14.205 - 14.290
Receive Antenna Gain (dB) FOV	34.9

Table 1. CTS Spacecraft Parameters (cont'd.)

Characteristics	Value
Uplink	
Receive System Noice Temperature (°K)	1285 paramp
	2025 TPA
Receive G/T dB/°K	6.81 on axis
	4.84 on axis
Transponder	
Transponder gain (dB)	122 high-powered channel
	111 low-power channel
Transponder bandwidth (MHz)	85
Frequency Plan	Translation offset frequency is 2.1666 GHz
Downlink	
Band of operation (GHz)	11.843 - 11.928 low-power
	12.038 - 12.123 high-power
Saturated output power (dBw)	22.4 high-powered channel
	11.8 low-power channel
Transmit gain (dB) FOV	33.9
Transmitted EIRP	56.30 high-powered channel
	45.70 low-power channel
Spacecraft General	
Pointing accuracy (degrees)	± 0.25
Station keeping accuracy NS (degrees)	none -- inclination increasing 0.8° per year.
EW (degrees)	± 0.25
Polarization	linear orthogonal transmit/receive

PSCS Characteristics

The transmission parameters and performance characteristics of the proposed PSCS spacecraft are summarized below in Table 2.

Table 2. PSCS Spacecraft Parameters

Characteristics	Value
Uplink	
Band of operation GHz	14.000 - 14.500
Receive antenna gain dB FOV	27.9 CONUS
(including plumbing loss of 1.0 dB)	33.5 regional
	38.5 offshore spots
	39.0 spots
Receive System Noise Temp. 817 °K	See Notes
29.1 dB/°K	
Receive G/T dB/°K (FOV)	-1.2 CONUS
	4.4 regional
	9.4 offshore spots
	9.9 spots
Transponder	
Transponder gain dB	to be determined
Transponder bandwidths MHz	10, 30, 100
Frequency plan	to be determined
Downlinks	
Saturated output power dBw	14.8
	20.0
Transmit Gain	
(including plumbing losses 1.0 dB)	26.3 CONUS
	31.9 regional
	36.9 offshore spots
	37.9 spots
EIRP FOV dBw	46.3 CONUS
	51.9 regional
	51.7 offshore spots
	52.2 spots

Table 2. PSCS Spacecraft Parameters (cont'd.)

Characteristics	Value
Spacecraft General	
Station keeping altitude control	Sufficient to allow unattended operation in a fixed position
Noise Temperature Notes	
1. NF =	4.5 dB
corresponds to T =	527.3°K
antenna temp. =	290° (earth view)
feed loss =	1.0 dB
T_{eff} =	$T_{lna} + \alpha T_{ant} + (1-\alpha) T_{amb}$
T_{amb} = 290°K =	527.3 + 0.79 x 290 + 0.21 x 290
α = 0.79	817.3°K 29.1 dB/°K
$G_{ant.\ net}$ =	34.5 - 1
	33.5 dB
G/T =	4.4 dB/°K
2. if $G_{ant.}$ =	39.5 dB
$G_{ant.net}$ =	38.5 dB
G/T =	9.4 dB/°K
3. if $G_{ant.}$ =	40.0 dB
$G_{ant.net}$ =	39.0 dB
G/T =	9.9 dB/°K
4. if $G_{ant.}$ =	28.9 dB
$G_{ant.net}$ =	27.9 dB
G/T =	-1.2 dB/°K

SYNCOM IV Characteristics

The transmission parameters of the 12/14 GHz portion of the proposed SYNCOM IV Spacecraft are summarized in Table 3.

Table 3. SYNCOM IV Spacecraft Parameters

Characteristics	Values
Uplink	
Bands of operation GHz	14.00 - 14.4
Receive antenna gain dB	32.5 Half CONUS
	35.9 Alaska Spot
	36.7 CONUS Spot
	39.0 Hawaii Spot
Receive System noise temp. °K	1150 includes TA, T_{feed} losses. Receiver NF 6.0 dB
Receive G/T dB/°K	1.4 Half CONUS
(Fe[illegible]s 0.5 dB)	4.8 Alaska
	5.6 CONUS Spot
	7.9 Hawaii
Transponder	
Transponder Gain dB	to be determined
Transponder bandwidth MHz	50
Frequency plan	See Attached
Downlink	
Saturated output power dBw	19 Half CONUS
(1 dB loss from TWT to antenna)	12 Regional and Alaska/Hawaii spots
Transmit antenna gain dB	32.5 Half CONUS
	34.7 Alaska Spot
	36.7 CONUS Spot
	38.6 Hawaii Spot
EIRP dBw	51.5 Half CONUS
	46.7 Alaska Spot
	48.7 CONUS Spot
	50.6 Hawaii Spot

Table 3. SYNCOM IV Spacecraft Parameters (cont'd.)

Characteristics	Values
Spacecraft G ˜al	
Station , .ping	not known but probably equivalent to current INTELSAT-IV A or COMSTAR.
Attitude Control	

SYNCOM IV Antenna Notes

1. Contours show actual gain levels
2. Half conus coverage

4 overlapping beams	
appear about 1.4° in diameter	
peak gain	41.5 dB 50% Efficiency
3 dB FOV	38.5 dB
1/4	32.5 dB

3. Regional Spots

beamwidth	1.2°
Gain peak	42 dB
FOV 3 dB	39 dB
Gain quoted is	36.6 dB
thus, there are losses	2.4 dB

blockage etc. due to multiple feeds.

SYNCOM IV G/T Notes

G = 32.5 including feed loss

0.5 dB feed loss

$T_R = 860°K$

$T_A = 290°K$

$T_{eff} = (0.89 \times 290) + (0.11 \times 290) + 860 = 1150$

VIDEO/AUDIO PARAMETERS

Emphasis was given to video parameters since they were more stringent in the requirements they imposed on the uplink/downlink station performance. The parameters are summarized in Table 4. In general, the definition and method of measurement for each parameter is given in CCIR Report 486.

Table 4. Video Parameters

Parameter	Performance Limit
Gain	
Insertion gain	0 dB ± 0.25 dB
Variations in gain	
(a) short-term (1 sec)	± 0.1 dB
(b) long-term (1 hr.)	± 0.2 dB
Linear Distortions	
Field time distortion	equal to or less than 2%
Line time distortion	equal to or less than 2%
Short-time waveform distortion	
(a) T Step response	equal to or less than 5%
Linear Chroma Distortion	
(a) Chrominance-Luminance gain inequality	equal to or less than 0.3 dB
(b) Chrominance-Luminance delay inequality	equal to or less than 30 μs
Non-Linear Distortions	
Luminance Non-Linear Distortion	equal to or less than 5%
Chroma Non-Linear Distortion	
(a) non-linear gain	equal to or less than 5%
(b) non-linear phase	equal to or less than 2°
Luminance to Chroma Intermodulation	
(a) differential gain	equal to or less than 3%

Table 4. Video Parameters (cont'd.)

Parameter	Performance Limit
(b) differential phase	equal to or less than 2°
Noise	
Random Noise (pp video to RMS weighted noise)	
(a) minimum	43 dB
(b) desired	48 dB
(c) optimum	53 dB

IMPACT OF RAIN ATTENUATION

At frequencies above 3 GHz, the attenuation of radio signals and the contribution to system noise temperature resulting from the absorption by atmospheric gases and water vapor become increasingly important and must be taken into consideration in the design of both the uplink and downlink portion of a satellite system. At 12 and 14 GHz, the significant factor is rain-generated attentuation and induced system noise temperature. The relationship between rain rates and resulting attenuation/noise has been the subject of extensive studies in recent years and research is ongoing. In particular, studies were undertaken using the ATS-5 and ATS-6 satellites and are being continued using the CTS and COMSTAR spacecrafts.

For the engineers designing a satellite system a useful design tool is the curve which statistically relates the probability of attenuation to the amplitude of that path attenuation.

Various models and approaches have been developed to estimate such a curve for a planned site. One such model is detailed in CCIR Report 234-2. Some of this model is used by the FCC in "Section 25" of its rules where it examines the impact of rain scattering of signals. Another approach was followed by Westinghouse Electric Corporation in their report entitled, "CTS Communications Link Characterization Experiment User Experiments Plan," of August, 1975. This report calculated rain margins required by both methods and examined the differences in result.

CCIR Report Method

The CCIR (and then the FCC) has assigned rainfall characteristics to the USA on a five-zone basis -- Zone I having the wettest rainfall characteristic and Zone 5 having the driest characteristic. These are tabulated in Figures 1 and 2.

Denver, Colorado is classified as being in Zone 2. The model calculation proceeds by using the elevation angle to estimate path length (through the rain) via the curve shown in Figure 3 and to estimate the rain attenuation per unit length for a given rain rate as shown in Figure 4. Thus, the likelihood of a given path attentution being exceeded can be estimated. The main shortcoming in this model is the assumption that the rain data characteristic is proper and for the actual site.

Westinghouse Report Method

Basically, this is a similar approach; however, it uses actual local rain data and instead of tabulated curves, uses a mathematical model for the attenuation calculation. The main shortcoming is that the local rain data is available only in a mean hourly form and needs processing to adjust for instantaneous characteristic. In the Westinghouse report, it is presumed valid to extrapolate the known differential experience at one site (at the Rosman, N.C.) to any site. Table 5 lists the rainfall data for the Denver airport while Figures 5 and 6 display rain data in both hourly and instataneous forms.

Table 5. Denver Rainfall*

Cumulative hours of rainfall at or exceeding a given rainfall rate for the 56,220-hour period from January 1, 1971, to May 30, 1977.

greater than 5.08 mm 61 hrs. (0.108%)	greater than 5.59 mm 50 hrs. (0.089%)
greater than 5.33 mm 54 hrs. (0.096%)	greater than 5.84 mm 44 hrs. (0.078%)

* All figures in Table 5 are equal to or greater than.

Table 5. Denver Rainfall (cont'd.)*

greater than 6.10 mm 39 hrs. (0.069%)	greater than 10.41 mm 15 hrs. (0.027%)
greater than 6.35 mm 37 hrs. (0.066%)	greater than 11.68 mm 14 hrs. (0.025%)
greater than 6.60 mm 36 hrs. (0.064%)	greater than 12.70 mm 13 hrs. (0.023%)
greater than 6.86 mm 33 hrs. (0.059%)	greater than 13.46 mm 11 hrs. (0.020%)
greater than 7.11 mm 32 hrs. (0.057%)	greater than 14.48 mm 10 hrs. (0.018%)
greater than 7.37 mm 28 hrs. (0.050%)	greater than 14.99 mm 9 hrs. (0.016%)
greater than 7.62 mm 25 hrs. (0.044%)	greater than 15.24 mm 8 hrs. (0.014%)
greater than 7.87 mm 22 hrs. (0.039%)	greater than 17.02 mm 7 hrs. (0.012%)
greater than 8.13 mm 21 hrs. (0.037%)	greater than 19.30 mm 6 hrs. (0.011%)
greater than 8.38 mm 20 hrs. (0.036%)	greater than 22.35 mm 4 hrs. (0.007%)
greater than 9.14 mm 18 hrs. (0.032%)	greater than 23.88 mm 3 hrs. (0.005%)
greater than 9.40 mm 16 hrs. (0.028%)	greater than 24.89 mm 2 hrs. (0.004%)
	greater than 39.37 mm 1 hr. (0.002%)

Rainfall Attenuation Calculations

In both approaches used, the attenuation was calculated at the 99.95% level, that is to say that, 0.05% of a given (long-term) period, the attenuation would be equal to or greater than that calculated. This corresponds to about 4.4 hours per year.

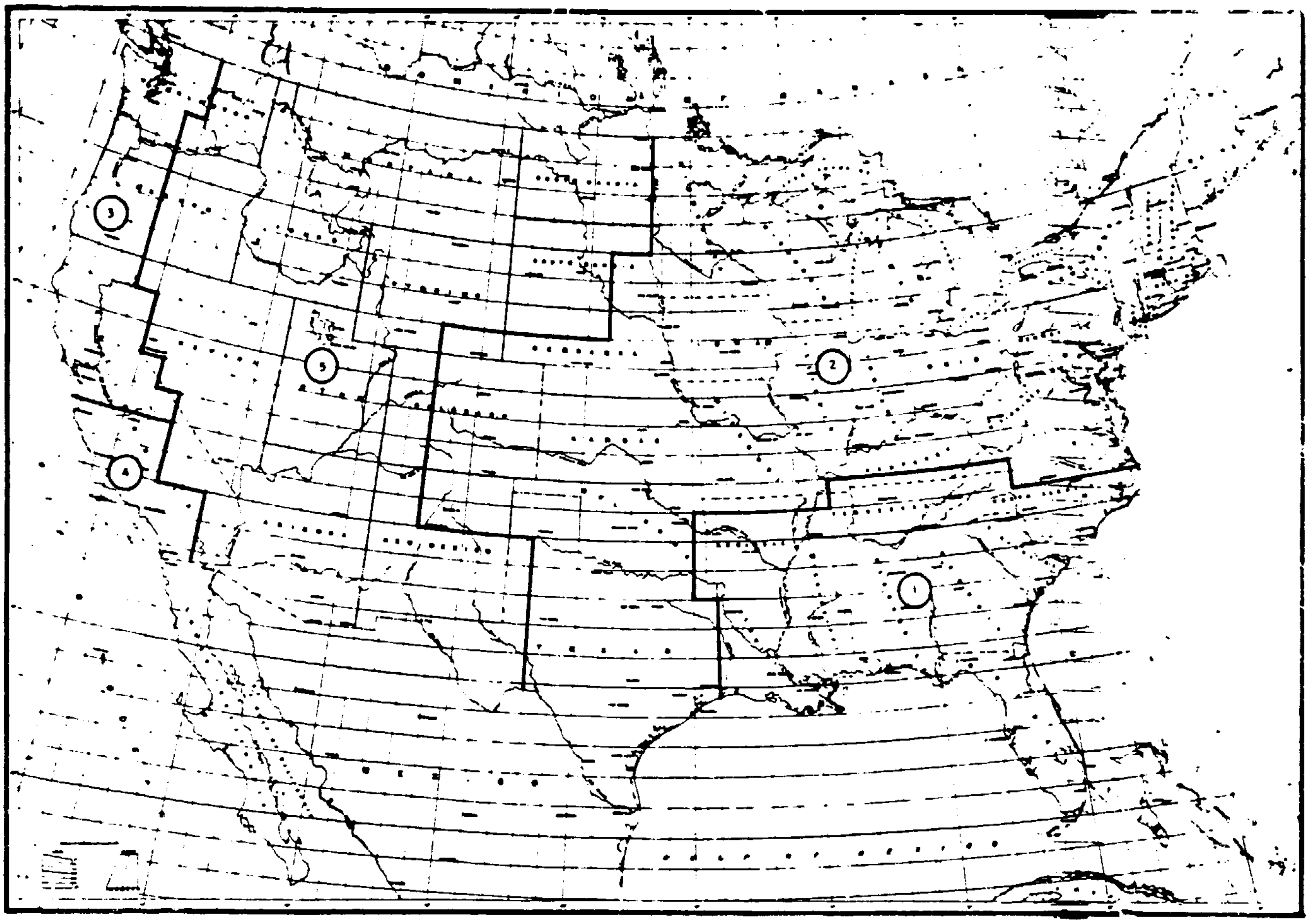
CCIR Approach

Denver categorized region 2/rain at 0.05% level region 2 = 20.8 mm/hr.
Attenuation/km at 12 GHz = 0.7 dB
Path length at 40° elevation = 3.75 Km
Total attenuation at 12 GHz = 2.63 dB
Attenuation/km at 14 GHz = 1.1 dB
Path Length = 3.75 Km
Total attenuation at 14 GHz = 4.1 dB

Westinghouse Approach

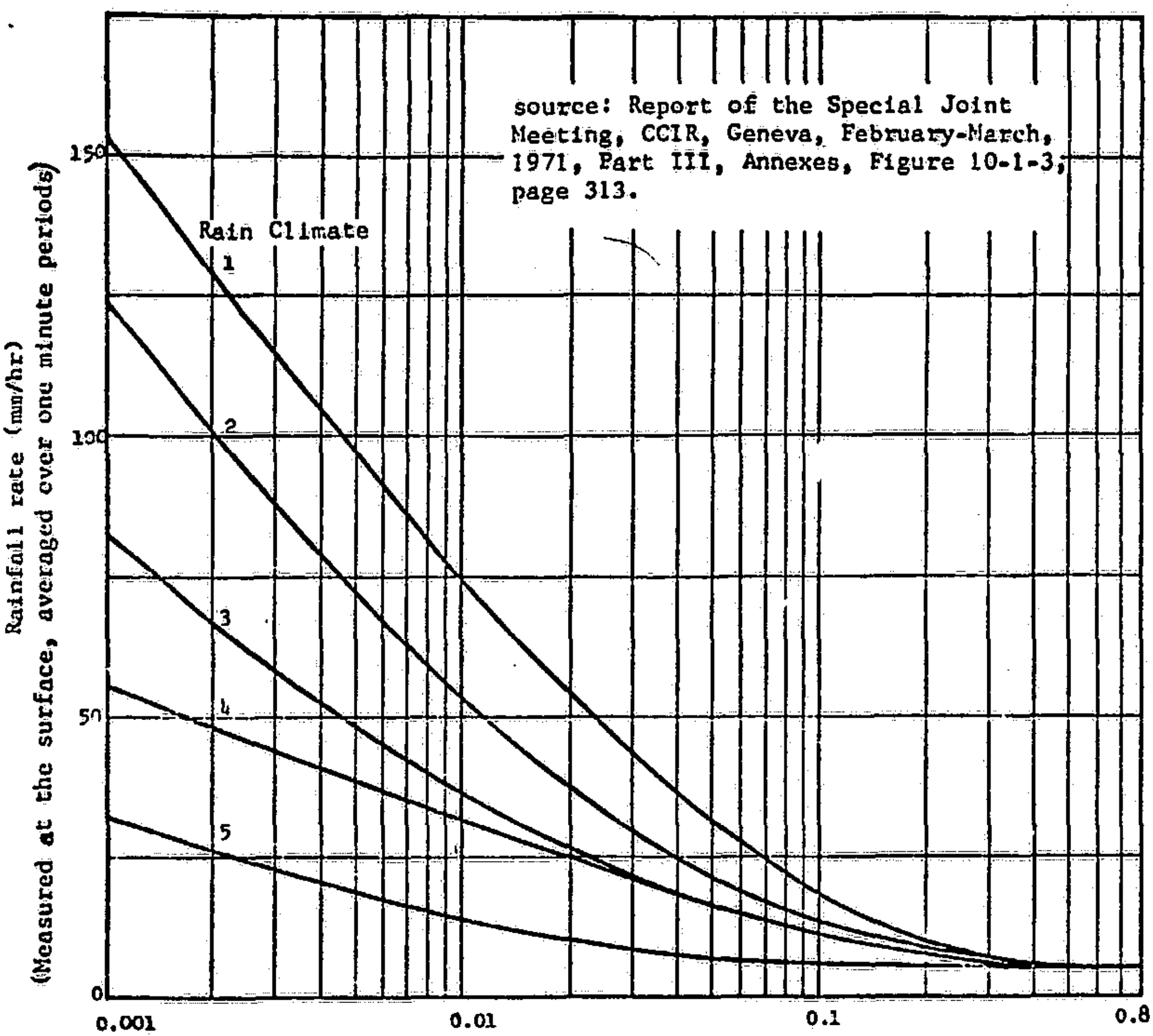
Corrected rain rate at 0.05% = 14.9 mm/hr.
Loss/km at 12 GHz = 0.49 dB
Path length = 8.00 Km
Total attenuation ≈ 3.92 dB

* All figures in Table 5 are equal to or greater than.



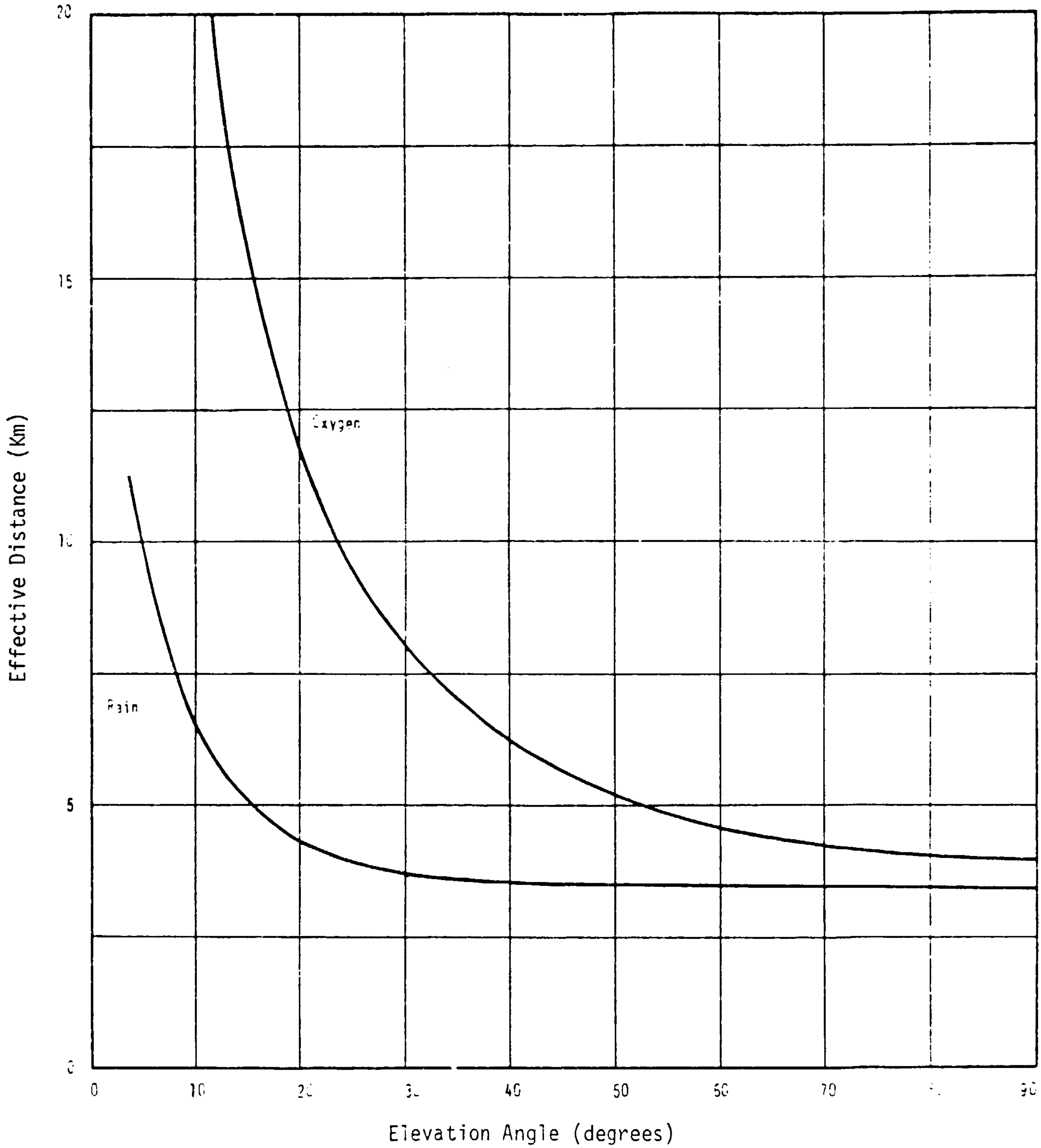
Source: FCC Regulations, Section 25

Figure 1. Rain Climates of the United States



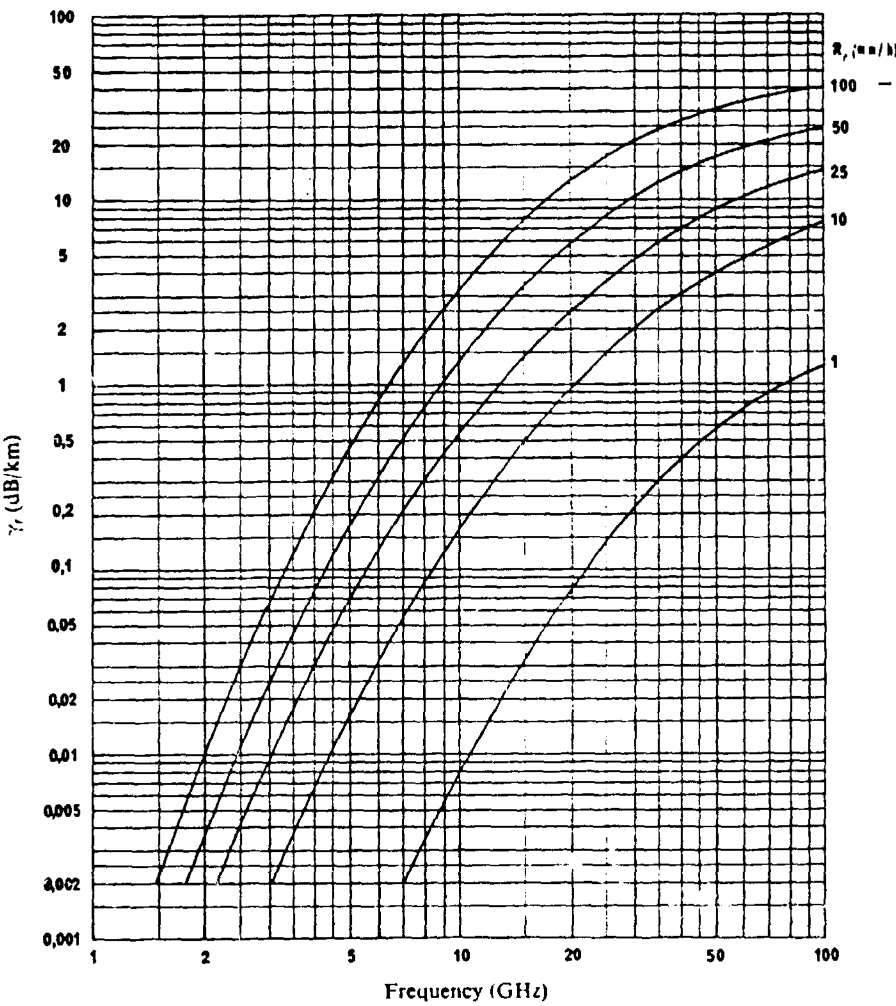
Percent of an average year for which the ordinate is exceeded for various Rain Climates

Figure 2. Distribution of Rainfall Rates for Several Rain Climates



Source: CCIR Special Joint Meeting, 1971

Figure 3. Rain Path Length Versus Antenna Elevation



Source: CCIR Report 234-2

Figure 4. Variation of Attenuation with Rain Rate and Frequency

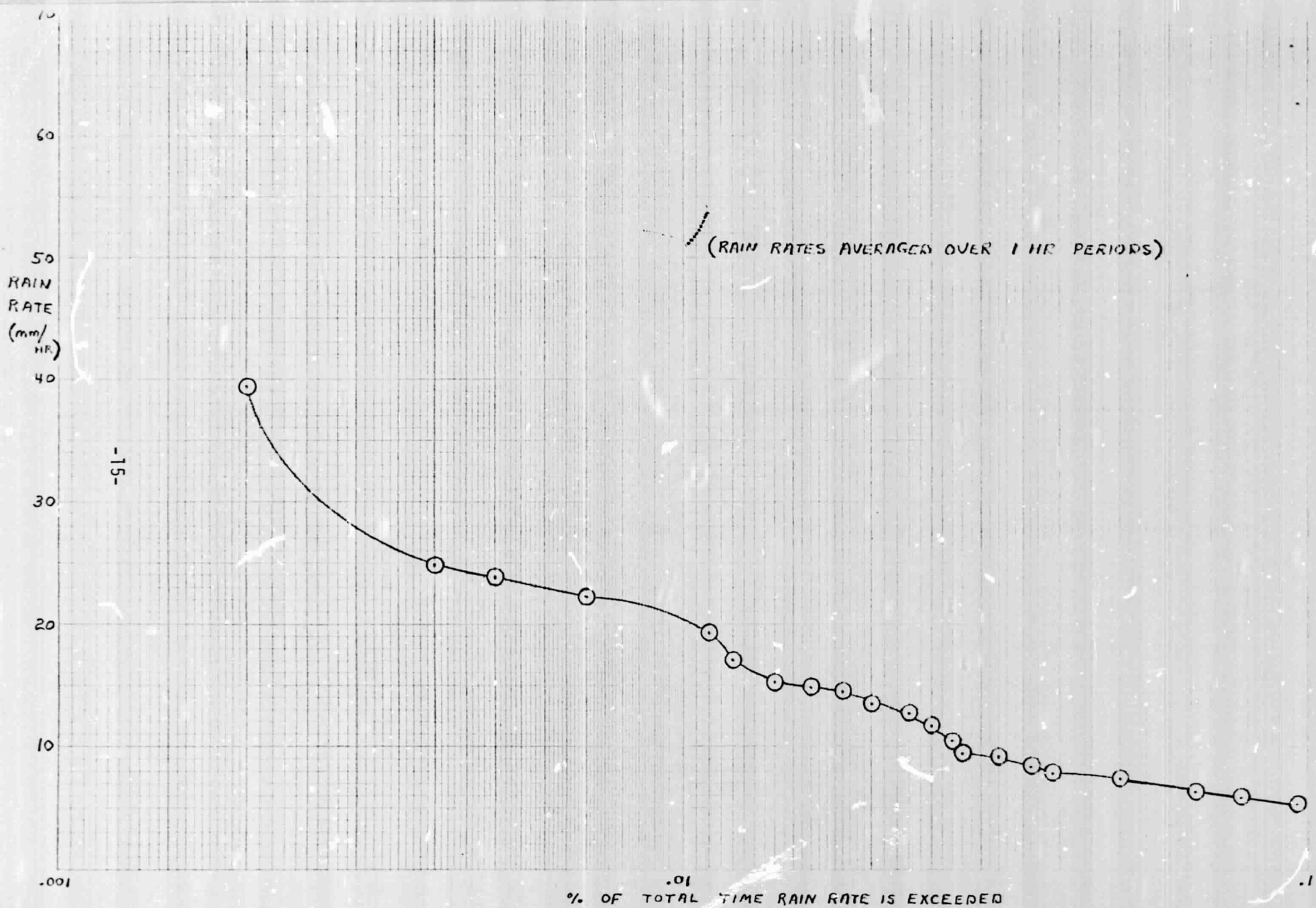


Figure 5. Denver Rain Characteristics (Rain Rates Averaged Over One-Hour Periods)

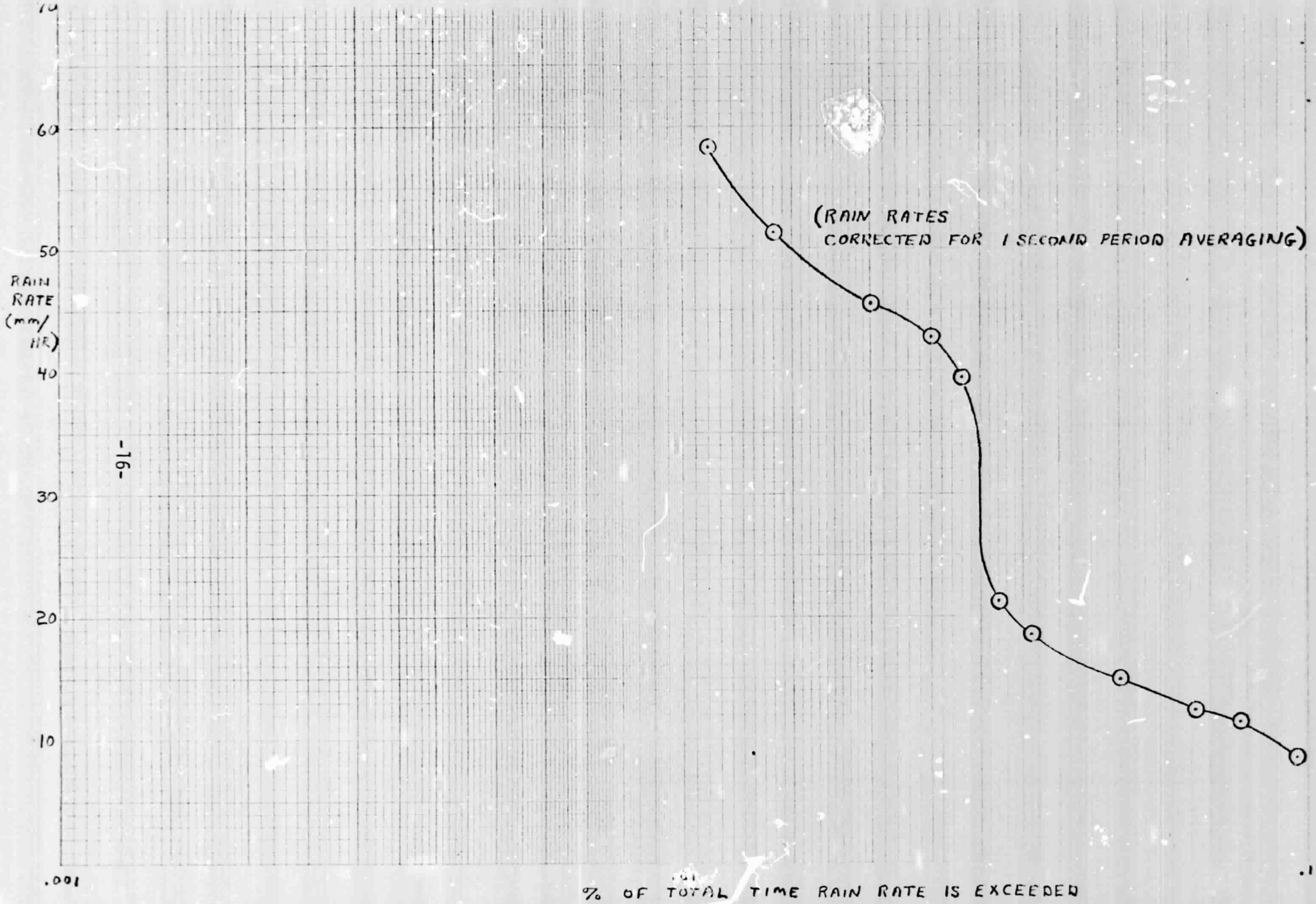


Figure 6. Denver Rain Characteristics (Rain Rates Corrected for One-Second Period Measurement)

Loss/km at 14 GHz = 0.66 dB

Path length = 8.00 km

Total attenuation = 5.28 dB

Summary of Results

12 GHz:

	Attenuation/km	Storm length	Attenuation
CCIR	0.7 dB	3.75 km	2.63 dB
Westinghouse	0.49 dB	8.00 km	3.92 dB

14 GHz:

	Attenuation/km	Storm length	Attenuation
CCIR	1.2 dB	3.75 km	4.1 dB
Westinghouse	0.66 dB	8.00 km	5.28 dB

For purposes of design, the following attenuations were assumed (as a probable conservative basis).

1. rain attenuation (12 GHz) = 4.0 dB
2. rain attenuation (14 GHz) = 6.0 dB

LINK CALCULATIONS

The number of different combinations of link calculations that could be carried out is probably infinite. The following are representative of boundary conditions and provide a basis for setting the parameters of the earth station design.

CTS

The difficulty in designing with CTS in a satisfactory manner is that uplink margins cannot be readily accommodated by use of increased uplink EIRP. The 200-watt TWT on CTS has overdrive protection which, when activated, will trip operation of the tube. It is conceivable that such an outage might be longer and more disconcerting than a noisy picture caused by a short burst of high rain rate. Consequently, operating uplink EIRP is basically set by requirements to saturate the 200-watt transponder under clear-sky conditions. The following calculations are based on this assumption:

Uplink to 200-watt transponder:

1.	Uplink frequency =	14.2471 GHz
	wavelength =	0.021043 m
2.	Subsatellite path loss =	206.6 dB
3.	Slant range loss =	0.55 dB
4.	Atmospheric loss =	0.30 dB estimated
5.	S/C Pointing loss =	0.25 dB $\pm$ 0.25°
6.	Off axis loss =	0.00 dB
7.	E/S Pointing loss =	1.00 dB
		208.7 dB
8.	S/C antenna receive gain =	37.9 dB
9.	Transponder gain =	122 dB
10.	Saturated output power =	22.4 dBw
11.	Uplink EIRP to saturate =	71.2 dBw

NOTE: A 6.0 dB uplink attenuation would cause an approximate reduction of 2.5 dB on the output of the 200-watt transponder.

12.	Operating bandwidth =	27 MHz
13.	Uplink C/N =	71.2 - 208.7 + 6 + 228.6 - 74.3
		= 23.6 dB

NOTE: If there is an uplink attenuation of 6.0 dB, uplink C/N would be 17.6 dB.

If downlink was to a minimum G/T station:

1.	Downlink frequency =	12.0805 GHz
	wavelength =	0.024817 m
2.	Subsatellite path loss =	205.2 dB
3.	Slant range loss =	0.55 dB
4.	Atmospheric loss =	0.30 dB
5.	S/C pointing error loss =	0.21 dB

6.	Off axis loss =	3.0 dB
7.	E/S pointing error loss =	1.0 dB
8.	Rain margin =	4.0 dB
		214.26 dB
9.	Receive station G/T =	14.5 (rainy sky)
10.	Downlink EIRP =	59.3 dBw
11.	Downlink C/N =	59.3 - 214.3 + 14.5 + 228.6 - 74.3
		= 13.8 dB
12.	Received C/N =	13.4 dB
13.	Received S/N =	47.8 dB pp video/weighted rms noise

Uplink to 20-watt Transponder:

1.	Uplink frequency =	14.2471 GHz
2.	Subsatellite path loss =	206.6 dB
3.	Slant range loss =	0.55 dB
4.	Atmospheric loss =	0.30 dB
5.	S/C pointing loss =	0.25 $\pm$ 0.25°
6.	Off axis loss =	0 dB
7.	E/S Pointing loss =	1.0 dB
		208.7 dB
8.	S/C antenna receive gain =	37.9 dB
9.	Transponder gain =	111 dB
10.	Saturate output power =	11.8 dBw
11.	EIRP to saturate =	71.60 dBw
12.	Operating bandwidth =	27 MHz
13.	Uplink C/N =	24.0 dB

Downlink to a high performance (G/T) station, (assuming downlink bore-signted on receive station).

1.	Downlink frequency =	12.0805 GHz
2.	Subsatellite path loss =	205.2 dB
3.	Slant range loss =	0.55 dB
4.	Atmospheric loss =	0.30 dB

5. S/C pointing error loss = 0.21 dB
6. Off axis loss = 0.0 dB
7. E/S pointing error loss = 1.0 dB
8. Rain margin = 4.0 dB

   211.3 dB
9. Receive station G/T = 23.1 dB/°K
10. Downlink EIRP = 48.7 dBw
11. Downlink C/N = 48.7 - 211.3 + 23.1 + 228.6 - 74.3

    = 14.8 dB
12. Received C/N = 14.3
13. Received S/N = 48.7 dB pp video/weighted rms noise.

Considerations of the downlink station requirements for CTS run as follows:

Downlink from 20-watt transponder:

1. Downlink frequency = 12.0805 GHz
2. Subsatellite path loss = 205.2 dB
3. Slant range loss = 0.55 dB
4. Atmospheric loss = 0.30 dB
5. S/C pointing error loss = 0.21 dB
6. Off axis loss = 0.0 dB
7. E/S Pointing error loss = 11.0 dB
8. Rain margin = 4.0 dB

   211.3 dB
9. If C/N total is greater than 12.0 dB, and uplink C/N = 23.6 dB, C/N down = 12.3 dB
10. Downlink EIRP = 48.7 dBw
11. Required G/T = 12.3 - 228.6 + 211.3 + 74.3 - 48.7

    = 20.6 dB/°K
12. Received S/N = 46.4 dB pp video/weighted rms noise
13. Received S/N = 50.4 dB pp video/weighted rms noise (under clear-sky conditions)

PSCS

The regional beams would be used for the video uplink. Using the same parameters for the path calculations as used for the CTS example.

1.	Uplink frequency =	14.2471 GHz
2.	Subsatellite path loss =	206.6
3.	Slant range loss =	0.55 dB
4.	Atmospheric loss =	0.30 dB
5.	S/C pointing loss =	0.25 dB
6.	Off axis loss =	0.0 dB (FOV G/T)
7.	E/S Pointing loss =	1.0 dB
		208.7 dB
8.	Spacecraft Receive G/T =	4.4 dB/°K
	assuming an uplink C/N of	20 dB:
9.	Uplink EIRP =	20 + 208.7 - 4.4 - 228.6 + 74.3
		= 70.0 dBw
10.	Rain loss =	6.0 dB
	if it were assumed that uplink C/N degraded to 17.0 dB during rain.	
11.	Required uplink EIRP =	73.0 dBw during rain.

Downlink consideration proceeds as follows:

Regional beam is assumed.

1.	Downlink frequency =	12.0805 GHz
2.	Subsatellite path loss =	205.2 dB
3.	Slant range loss -	0.55 dB
4.	Atmospheric loss -	0.30 dB
5.	S/C Pointing error loss =	0.21 dB
6.	Off axis loss =	0.0 dB (FOV EIRP assumed)
7.	E/S Pointing error loss =	1.0 dB
8.	Rain margin =	4.0 dB
		211.26 dB
9.	Downlink EIRP =	51.9 dBw FOV

10. Assuming downlink C/N of
13 dB, G/T = 13 - 51.9 + 211.26 - 228.6 + 74.3
= 18.06 dB/°K

11. Assuming uplink C/N of
20 dB, Received C/N = 12.21 dB

12. Received S/N = 46.61 dB pp video/weighted rms noise

<u>SYNCON IV</u>

Uplink to half CONUS beam

1.	Uplink frequency =	14.2471 GHz
2.	Subsatellite path loss =	206.6 dB
3.	Slant range loss =	0.55 dB
4.	Atmospheric loss =	0.30 dB
5.	S/C pointing loss =	0.25 dB
6.	Off axis loss =	0.0 dB (FOV EIRP assumed)
7.	E/S pointing loss =	1.0 dB
		208.7 dB
8.	Spacecraft receive G/T =	1.4 dB/°K
9.	Rain margin =	6.0 dB
	assume uplink C/N =	15.0 dB
10.	EIRP required =	15 + 214.7 - 1.4 - 228.6 + 74.3
		= 74.0 dBw

Downlink from half CONUS beam

1.	Downlink frequency =	12.0805 GHz
2.	Subsatellite path loss =	205.2 dB
3.	Slant range loss =	0.55 dB
4.	Atmospheric loss =	0.30 dB
5.	S/C Pointing error loss =	0.15 dB
6.	Off axis loss =	0.0 dB FOV EIRP
7.	E/S Pointing error loss =	1.0 dB
8.	Rain margin =	4.0 dB
		211.20 dB
9.	Downlink EIRP	51.5 dBw

10. If C/N total is 12.0 dB, and C/N up is 21.0 dB*, C/N down is 12.6 dB,

G/T required = 12.6 + 211.2 - 51.5 + 74.3 - 228.6
= 18.0 dB

*NOTE: Simultaneous rain on uplink and downlink has been assumed to be statistically not important and so uplink C/N has been increased by the rain margin.

Summary of Requirements

	CTS		PSCS	SYNCOM IV
	20W	200W	Regional	
Uplink EIRP (dBw)	71.6	71.2	73.0	74.0
Downlink G/T dB/°K	20.8	13.8	18.1	18.0

If the receive G/T of 20.8 dB/°K is selected, then the 74.0 dBw EIRP requirement of SYNCOM IV can be relaxed to about 71.8 dBw. Similarly for the case of the PSCS.

Optimization Considerations

The worst case combination of requirements lead to the following basic earth station parameters:

A. Receive G/T: 20.8 dB/°K (during rain)

B. Transmit EIRP: 71.8 dBw

A range of earth station antenna sizes ranging from 6 feet to 15 feet in diameter were considered. The receive low-noise amplifier temperatures and transmitter output powers to achieve the required performance are presented in Table 6. The following common parameters were assumed:

1. Receive feed W/G loss = 0.5 dB
2. Sky temperature during rain = 150°K

3. Effective antenna temperature

$T_e = \alpha \, (T_s + T_{ant}) + (1 - \alpha) \, T_{ambient}$

Where α = 0.89 (0.5 dB)

T_s = 150°K

$T_{ant.}$ = 30°K

Thus, T_e = 192°K

4. Transmit line losses = 0.75 dB

Table 6. Possible Earth Station Combinations

Diameter Feet	Receive Gain	LNA Temp.	Transmit Gain	Transmitter Power
6	44.3	31.6°K	45.3	447W
8	46.7	196.7°K	47.8	251W
10	48.7	424.3°K	49.8	159W
12	50.2	678.6°K	51.3	112W
15	52.2	1188.1°K	53.3	71W

The six-foot antenna was eliminated for reason of the very low LNA temperature required and the costly HPA. The 15-foot dish would require a major installation effort for a roof mount (see following Section on site selection). HPA's are currently available either with Klystrons or TWT's. The lower-cost TWT form is available in sizes up to a power of about 200 watts. In addition Ga As FET low-noise amplifiers are now available at low cost with about 4.0 dB NF (438°K). An optimum solution thereby appears to be either with the 10-foot dish or 12-foot dish. If the dish feed were cassegrain, the receive feed losses could be reduced below those assumed for Table 6. In this way, a ten-foot dish would achieve the required G/T performance. In addition, transmit line losses would be minimized and polarization adjustment facilitated.

Recommendation

dish size -- 10-feet diameter

feed -- cassegrain

LNA -- 4 dB NF

HPA -- 200 W TWT

SITE SELECTION

INITIAL CONSIDERATIONS

The Diamond Hill Office Complex, where the Network Coordinating Center (NCC) is located, is a complex of four office buildings located within the Denver city limits and is separated from the downtown commercial district by a north/south interstate freeway. Because of Diamond Hill's location within a confined urban area, ground mounting of an antenna is virtually impossible due to lack of available space and aesthetic considerations imposed by the landlord. Therefore, site selection concentrated on a roof mount location for the antenna on Building B of Diamond Hill, the building within which the NCC is located.

Structural blueprints of the building were obtained from the landlord, and in consultation with the landlord's chief engineer, it was determined that the nine-inch thick concrete roof of the building would withstand the 125 MPH wind loads (with 1.5 safety factor) of the proposed antenna (see Appendix A, Antenna Foundation Loads). Cable entry into the building could be accomplished without difficulty through existing cable entry points (both the landlord's, and PSSC microwave and VHF entry points), and once in the building, cables could be run to the NCC (located on the ground floor) via the building's main electrical/telephone conduits. AC power was readily available in the mechanical rooms on each floor located in conjunction with the building's main conduits. A roof location also offered restricted access for the purposes of protection of the general public from harmful radiation. Therefore, the roof mount location to be selected was restrained by three considerations:

1. look angle to the CTS and other future satellites;
2. available access for maintenance and observation; and
3. landlord aesthetic considerations.

FIRST PROPOSED LOCATION

A location on the second floor roof level, south end of the building, was selected. As may be seen in Appendix B, this location offered unobstructed pointing at the CTS satellite at its present orbital position of 116° W longitude, as well as an unobstructed pointing arc of 70° to 150° W longitude. Although the FCC recommended pointing arc is 70° to 135° W, an extension of the arc to 150° W is desirable to permit operations with a satellite serving the U.S. Trust Territories in the Pacific. This location also offered immediate access through a door directly adjacent to the elevator lobby on the third floor. A formal request for permission from the landlord to construct the antenna at this location was submitted and is contained in Appendix C. (This request also contains proposed locations for VHF audio/data antennas as well. A separate analysis of VHF capabilities had resulted in the need for action concerning the location of these antennas, and the VHF location question was combined with the wideband 12/14 GHz location to facilitate negotiations with the landlord.)

SECOND PROPOSED LOCATION

A series of meetings with the landlord followed the original request, at which the landlord communicated a "strong desire" that the antenna not be located as proposed because it would be visible to the complex buildings to the east of Building B. A new location was then selected on the third floor, on the west side of the building's penthouse (where the building's airconditioning and heating units are located). This new location eliminated the antenna's view from the buildings to the east, offered access through a door from the penthouse, and still maintained a pointing arc of 70° to 150° W longitude (see Appendix D).

APPROVAL TO CONSTRUCT

The formal request to the landlord for permission to construct was amended to reflect the antenna's location on the third floor roof, and the landlord subsequently granted approval (see Appendix E).

Appendix A. Antenna Foundation Loads

Without detailed knowledge of the design of the mount for the antenna, it is impossible to predict with certainty the forces that the antenna will deliver to its foundations under wind loaded conditions. One can, however, calculate the total load to be transmitted by the total foundation system as it is the load generated by the wind on the parabolic section of the antenna.

Using the technique outlined by Brown and McKee, ("Wind loads on Antenna Systems," the Microwave Journal, September, 1964), the total loads to be transmitted by the antenna were estimated for the survival wind of 125 MPH with a 1.5 safety factor.

1. Force Equations:

   $F = A\ C_R\ q$

   Where:

   F = drag force in pounds

   A = projected area in square feet

   C_R = resultant drag coefficient

   q = dynamic pressure in pounds per square foot

   Where:

   $q = \frac{\rho v^2}{2}$

   Where:

   ρ = mass density of air

   v = wind velocity

2. Corrections for Altitude and Temperature:

   Since the density of air varies with temperature and elevation above sea level, adjustments must be made for these factors.

   Altitude -- 5,000 ft. AMSL

   Low Temperature -- -20° F (-28.9°C)

   At standard temperature (15°C) and 5,000 feet altitude,

   $q = 0.00210\ V^2$ approximately, and at -20° F,

   $q = 0.0021 \times \frac{288.0}{244.1} V^2 = 0.00248\ V^2$

3. Force Computation

$F = A\ C_R\ q$

$A = 78.54$ sq. ft.

$C_R = 2$

$q = 0.00248\ V^2$

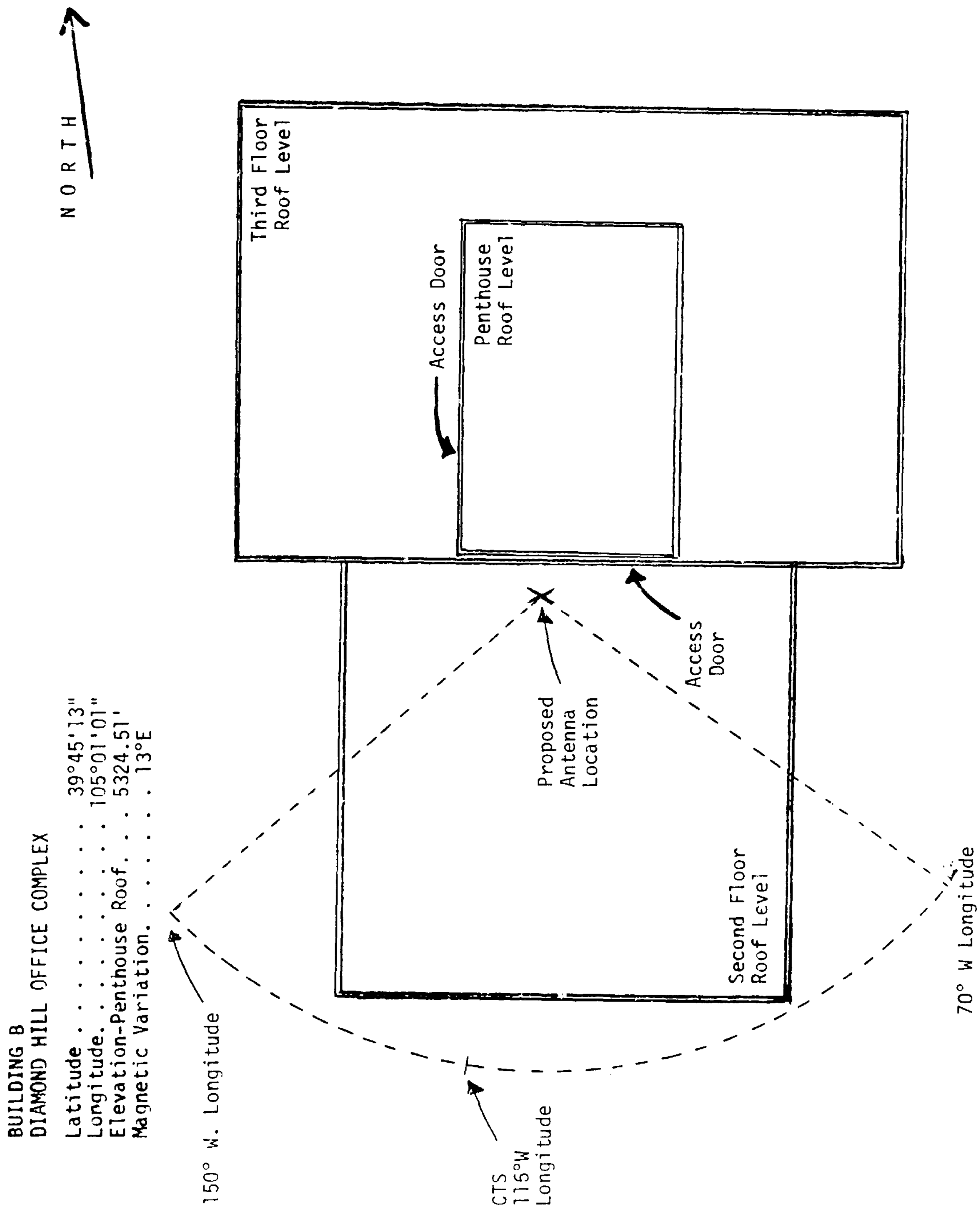
With 125 MPH survival condition, 1.5 safety factor

V = sq. root of 1.5 x 125 = 153 MPH.

$F = 78.54 \times 2 \times 0.00248 \times 153^2 = 9119$ lbs.

The resultant force used for site loading was 10,000 lbs.

Appendix B. Antenna Location, Second Floor Roof



Public Service Satellite Consortium

February 1, 1977

Mr. Jim Sutton
Management Office
Diamond Hill Office Complex
Denver, Colorado 80211

Dear Jim:

This is a request to allow the Consortium to install two (2) additional communications antennas and to relocate one of our existing antennas on the roof of Building B. Specifically, we request approval to:

1) Relocate the existing VHF helical antenna from its present position on the roof of the penthouse to a new location on the third floor roof, west side of the penthouse; and add a new VHF helical antenna to be located on the third floor roof, west side of the penthouse. The proposed locations are shown on Figure 1.

2) Add a parabolic antenna to be located on the second floor roof shown on Figure 1.

Figure 2 contains a description of the VHF helical antennas, and Figure 3 shows the proposed method of installation for these antennas. The proposed location of these VHF antennas adjacent to the west wall of the penthouse will make them virtually invisible from all directions except the west parking lot. Cable access into the building will be accomplished through an existing wall opening in the west wall of the penthouse.

Figure 4 contains a description of the parabolic antenna, and Figure 5 shows the proposed method of installation for the parabolic antenna. The proposed location of this antenna adjacent to the south wall of the third floor will reduce the visibility of the structure as well as reduce the wind loading to which the structure will be subjected. Visibility observations were taken using a 12 foot pole located at the proposed location. The pole was not visible from the ground level main entrance to Building C. Cable access into the building will be accomplished through an existing wall opening in the south wall of the third floor. A catwalk will be installed from the access door to the antenna to protect the roof.

PRINCIPAL OFFICES:
[illegible] VALLEY BOULEVARD
[illegible] AVENUE
1126 16th STREET, N.W.

Mr. Jim Sutton February 1, 1977

Your prompt attention to this request will be greatly appreciated.

Sincerely,

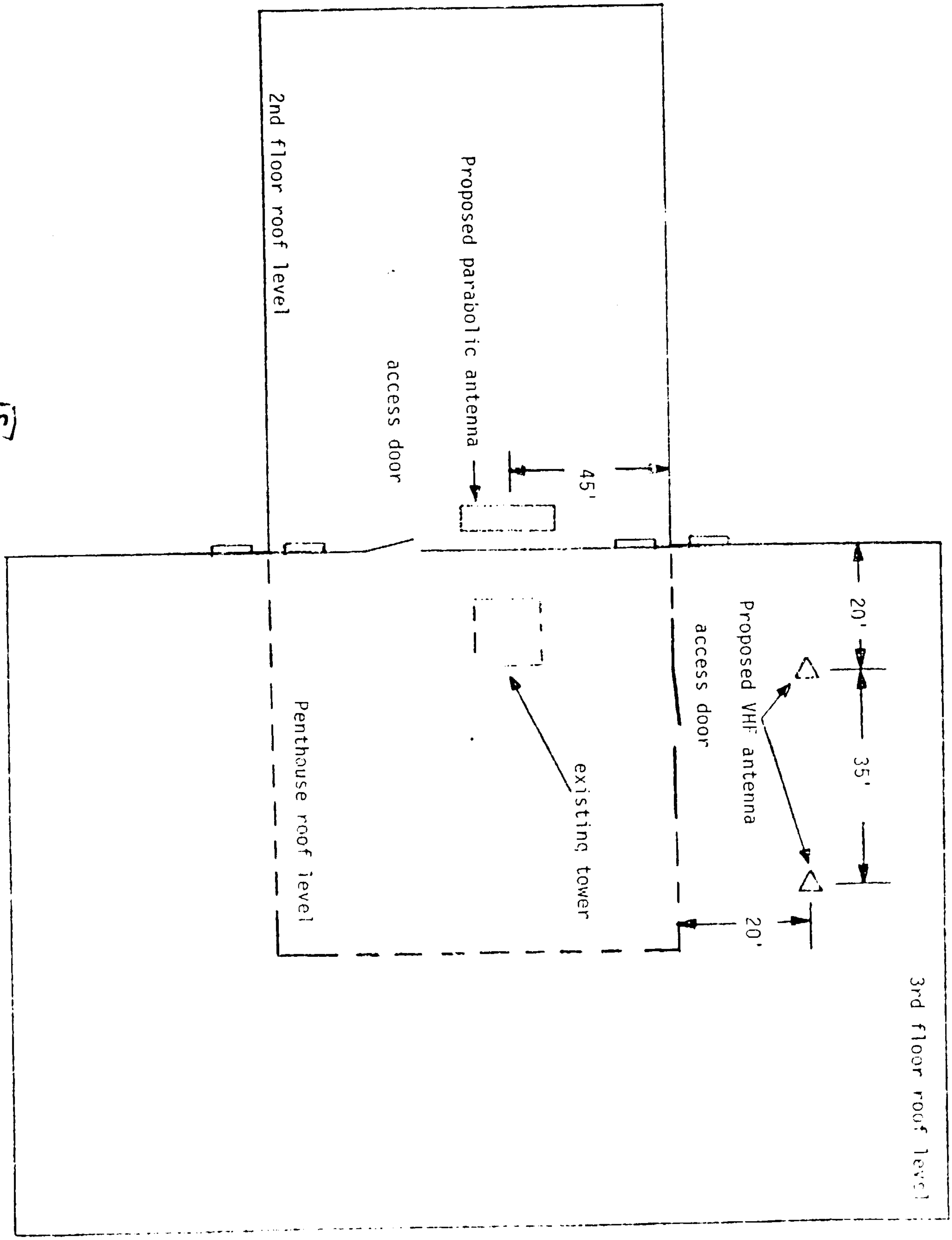
Dail Ogden

DAIL OGDEN
Director
Engineering

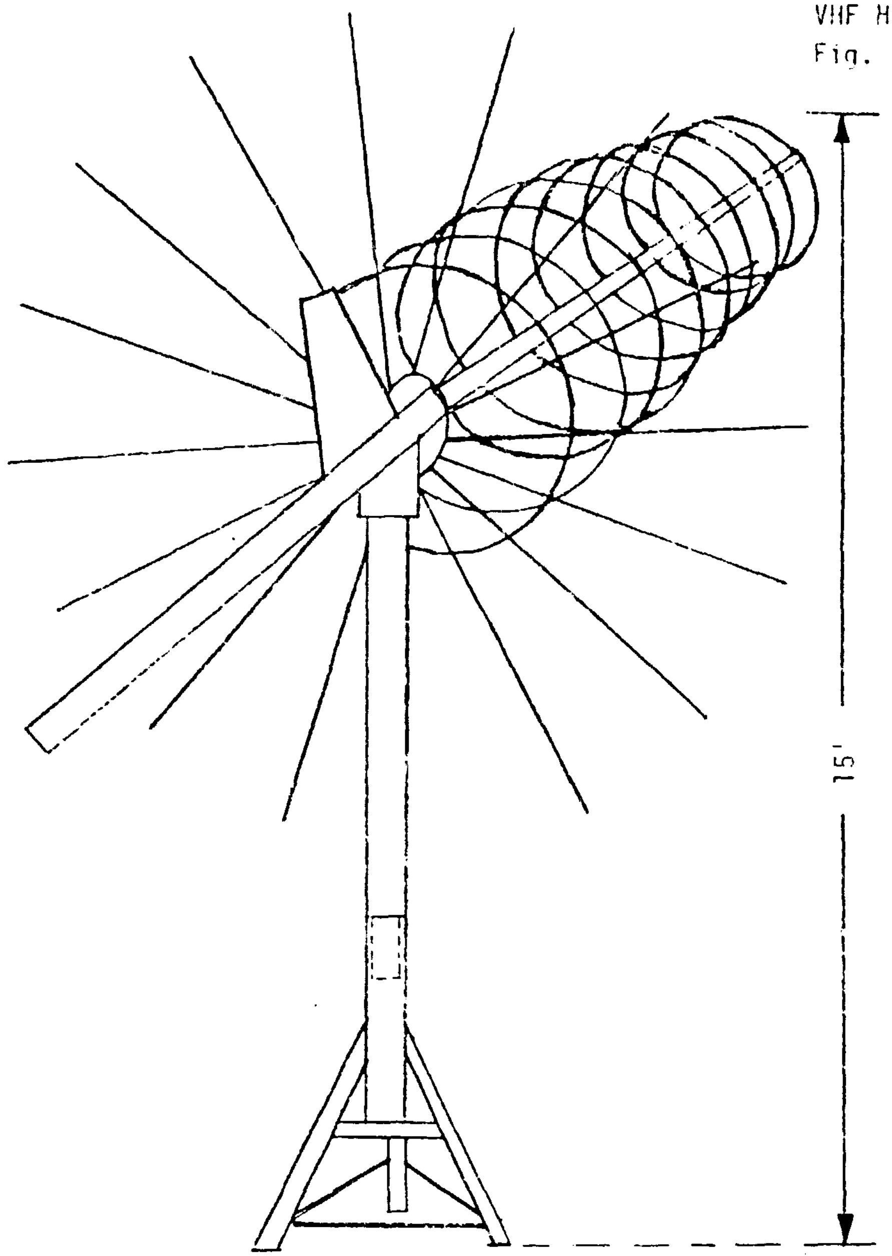
DO:rcb
attach.

Proposed Antenna Location
Building B

Fig. #1



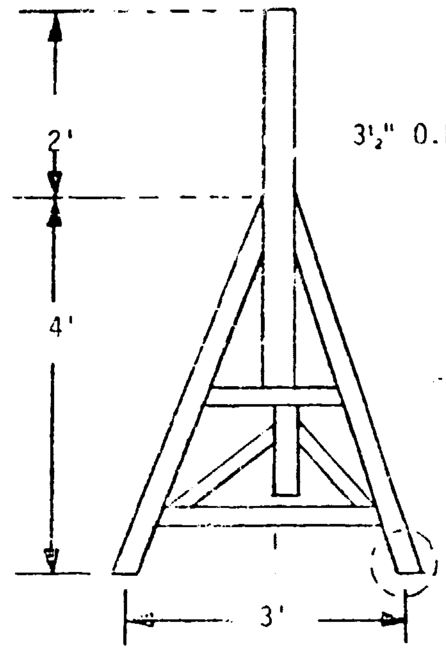
VHF Helical Antenna
Fig. #2



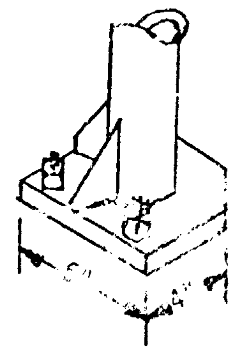
1. Height above roof level = 15'
2. Dead weight = 200 lbs.
3. Wind loading (150 mph) = 1,000 lbs.
4. Antenna orientation - Azimuth (1) 170° (true)
   (2) 237° (true)
   Elevation (1) 44°
   (2) 26°
5. See Figure #3 for mounting to roof

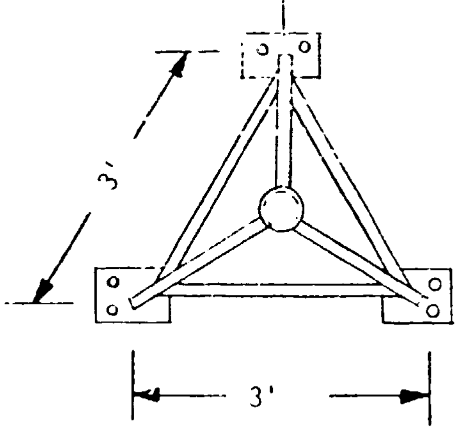
Proposed VHF Helical
Antenna Installation

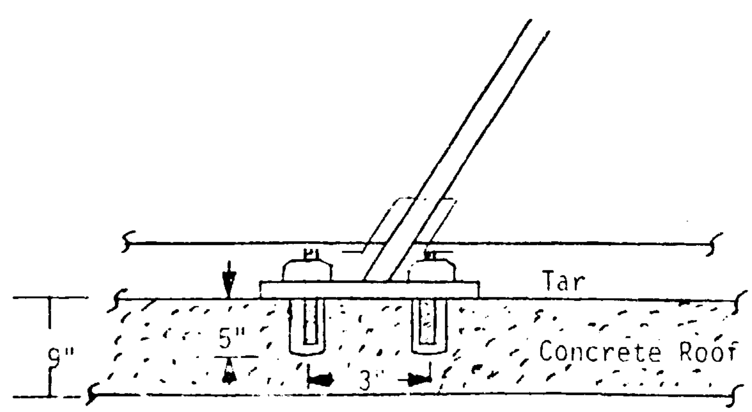
Fig. #3



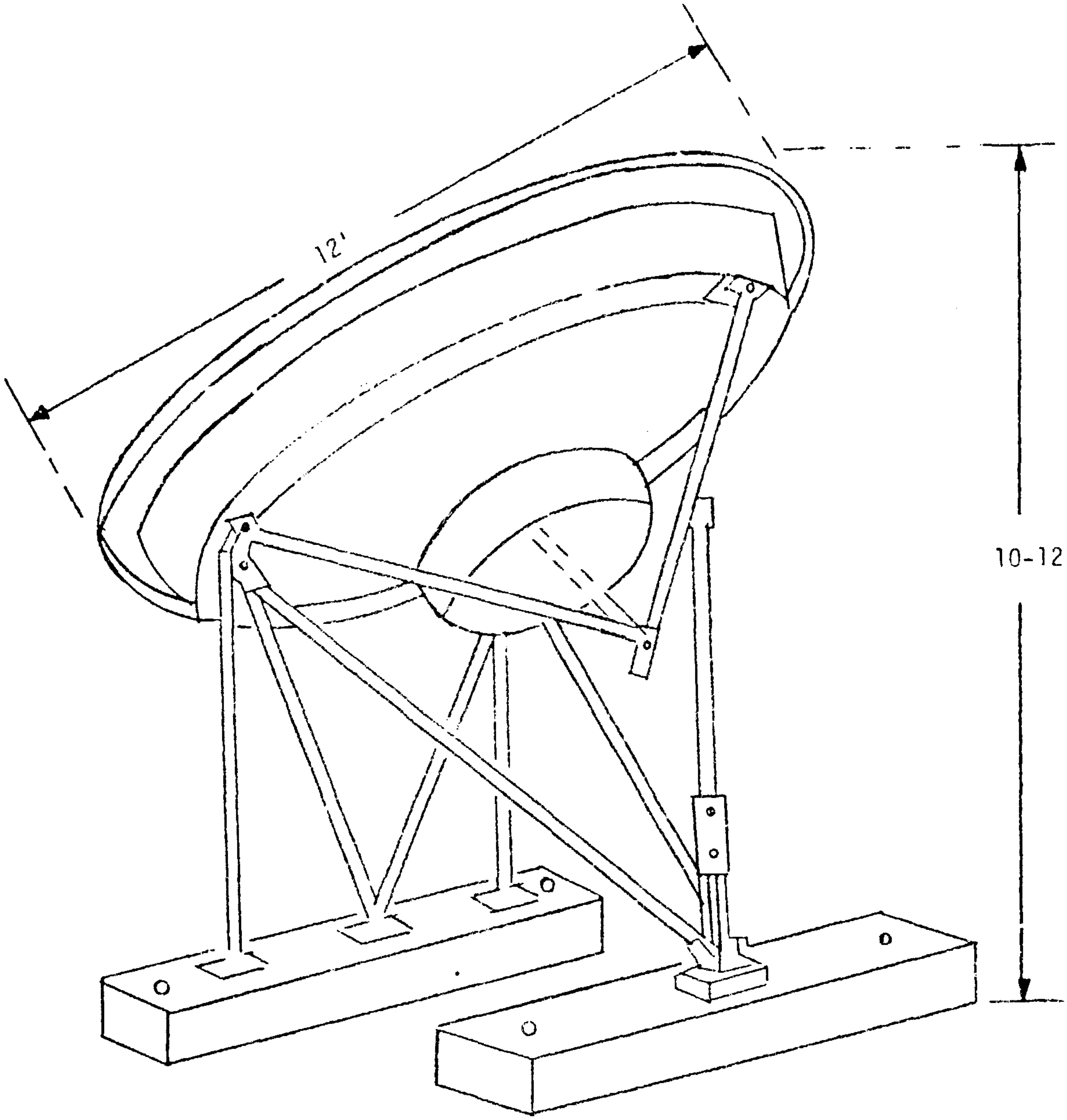
Detail "A"
Typ. 6 Places







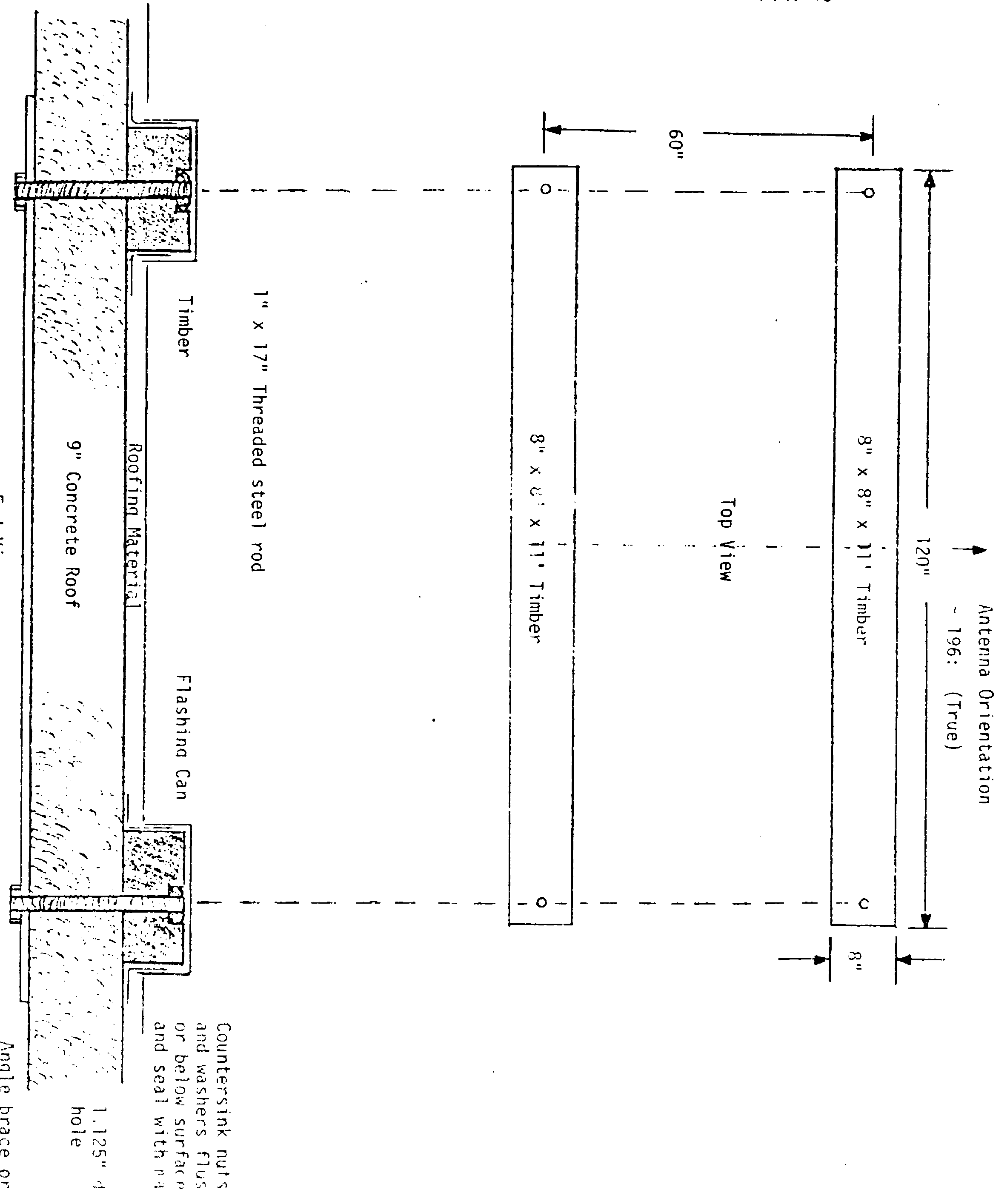
1. Cut out or roll back roofing - 6" square
2. Drill 1" dia. hole 5" deep.
3. Secure 5/16" x 6" bolt in predrilled hold with poor-rok or equivalent (6 places)
4. Install flashing and cover mounting brackets and bolts with hot tar or approved roofing material.



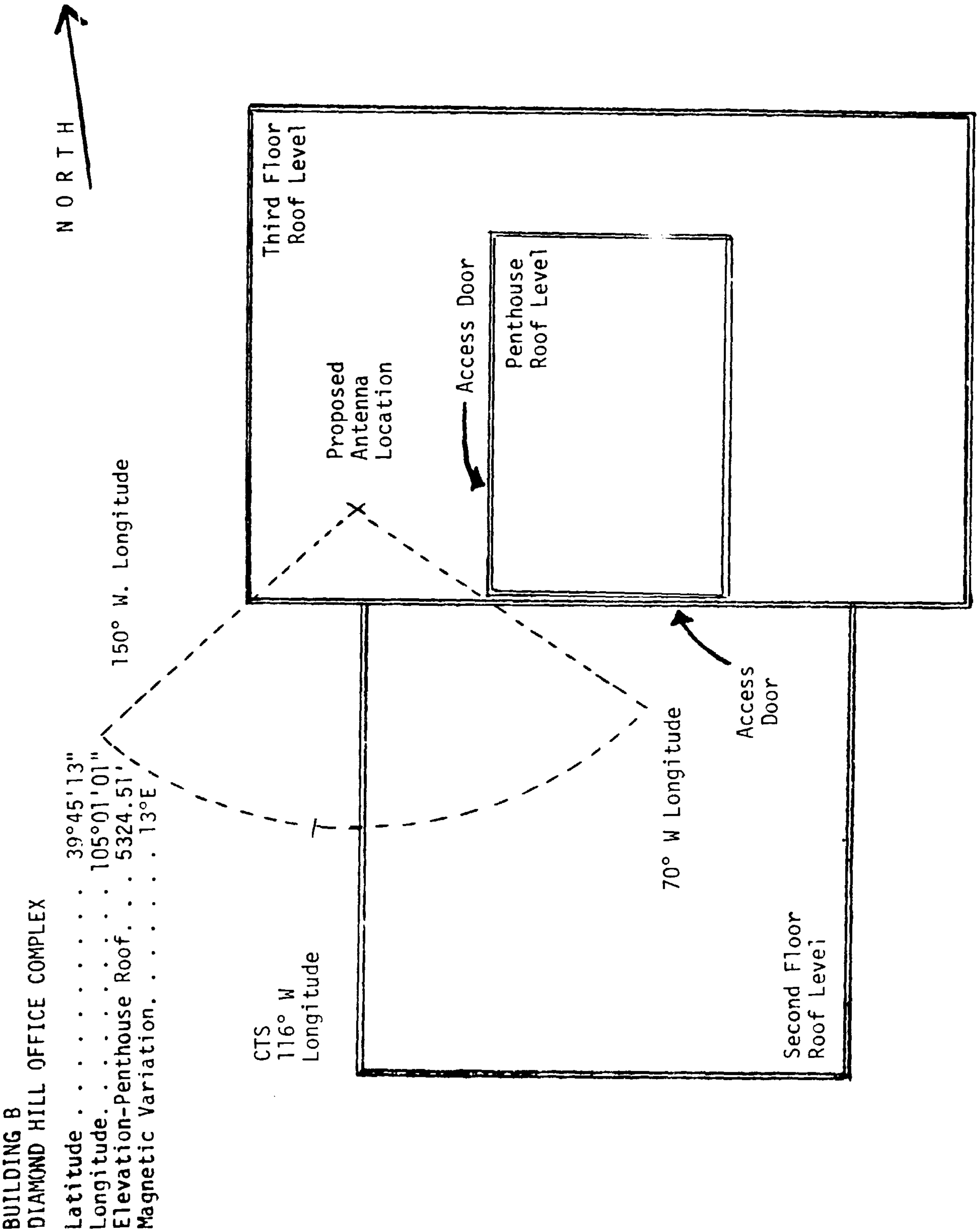
1. Height above roof level = 12'
2. Dead weight = 750 lbs.
3. Wind loading (150 mph) = 8,000 lbs.
4. Antenna orientation - Azimuth = 196° (true)
   Elevation = 43°
5. See Figure #5 for mounting to roof

Proposed Parabolic
Antenna Installation

Fig. #5



Appendix D. Antenna Location, Third Floor Roof



February 18, 1977

Mr. Jim Sutton
Management Office
Diamond Hill Office Complex
Denver, CO 80211

Dear Jim:

Re: My letter of February 1, 1977, requesting authorization for antenna installations on the roof of Building B

Per your request that the Consortium reevaluate the proposed locations for its communications antennas, attached is a revised Figure 1 showing our new proposed locations. All three antennas are now located on the third floor roof to the west of the penthouse structure. The antennas will be surrounded by a 25'x25' enclosure consisting of 4 corner posts (not exceeding 4' in height) supporting a barrier cable. Warning signs will be hung on the cable on each side of the enclosure. At this location, the three antennas are not visible from any windows in either Buildings C or D.

The proposed 12 foot parabolic antenna is a major technological development in satellite communications. This antenna can accomplish the same functions as "older" versions of antennas which are 40 to 50 feet in diameter and must be located outside urban areas (due to size and radio frequency interference). It is important to both the Consortium and to the National Aeronautics and Space Administration (our source of funding) that visitors to our facilities be able to view this new type of antenna. It was for this reason that we had originally proposed locating the antenna on the second floor roof where access was readily available through the door located by the elevators on the third floor. Therefore, we agree to the new location on the third floor roof, subject to the condition that Diamond Hill authorize the Consortium access to the antenna through the penthouse for the purpose of showing the antenna to visitors (as well as for routine maintenance).

Sincerely,

DAIL OGDEN
Director
Engineering

DO:rcb

Approved:

Diamond Hill Office Complex

2/23/77
Date

PRINCIPAL OFFICE:
[illegible] VALLEY BOULEVARD
[illegible] CALIFORNIA 92121
[illegible]

2480 WEST 26th AVENUE
DENVER, COLORADO 80211
[illegible]

[illegible] STREET, N.W.
WASHINGTON, D.C. [illegible]
[illegible]

Proposed Antenna Location

Figure 1

Revised 2/15/77